SANDIA FREQUENCY SHIFT BASED ARTIFICIAL IMMUNE SYSTEM FOR ANTI-ISLANDING DETECTION

A.Y.Hatata[1], El-H.Abd-Raboh[2] Bishoy.E.Sedhom[3]
Faculty of engineering, Mansoura University, Egypt
eng_bishoy90@yahoo.com

Abstract— **This paper presents a new method for islanding detection. The proposed method depends on applying an artificial intelligence method based artificial immune system (AIS) with sandia frequency shift (SFS) method. AIS is used to improve the performance of the SFS method including the improvement of the system power quality, reduction in non-detection zone (NDZ) and reducing the islanding detection time. The proposed method is tested and applied to a test system and the results show that the proposed method is more efficient in islanding detection.**

Index Terms— **Anti-islanding Detection, Sandia Frequency Shift (SFS), Non Detection Zone (NDZ), Total Harmonic Distortion (THD), Artificial Immune System (AIS), Clonal Selection Algorithm.**

I. INTRODUCTION

Distributed generations (DG) are small-scale generation units that can be installed near to consumers with the ability of interacting with the grid importing or exporting energy. One of the major problems associated with such generators is the unwanted islanding phenomenon. Islanding occurs when a portion of the distribution system becomes electrically isolated from the remainder of the power system yet continues to be energized by one or more DGs. An important requirement to interconnect a DG to a power distributed system is the capability of the DG unit to detect islanding with the minimum time possible. The continued energizing of the load can lead to damage of equipment or injury to maintenance personnel working within the islanded section without knowing the system is still alive. Most DG units are designed in such a way that they will disconnect from the grid when over/under voltage or frequency occurs on the network. In the case that the grid is disconnected while the load and the source are matched, the DG units will thus continue to power the line, thereby leading to the formation of an island.

DGs must detect islanding and immediately stop feeding the utility lines with power. This is known as anti-islanding. Anti-islanding methods assist the DG units to detect islanding or force the islanded section out of the normal operational specifications of the grid. This is achieved by attempting to perturb either the voltage or the frequency of the network. In the presence of the grid, these perturbations will have no effect on the voltage or frequency. If the grid is disconnected, though, variations in voltage or frequency can occur. These variations can be detected by the over/under voltage or frequency protection system, and the DG is disconnected or shutdown.

Anti-islanding methods generally can be classified into four major groups, which include passive methods, active methods, hybrid methods and communication base methods [1]. Passive methods monitor selected parameters, such as voltage, frequency or their characteristics, and they switch off the inverter if one of these parameters deviates outside specified boundaries or conditions [2].The boundary limits of these parameters define the non-detection zone (NDZ). The passive methods include: Over/Under Voltage Protection (OVP/UVP), Over/Under Frequency Protection (OFP/UFP), voltage phase jump detection, and detection of voltage and current harmonics methods [3-4]. These methods are conceptually simple and easy to implement and do not introduce any change to the power quality of the system. However, they have a number of weaknesses including the inability to detect islanding because they have a large NDZ. They tend to false trip due to disturbances on the grid which may weaken grid stability and security.

In order to reduce the NDZ, particularly in cases where the local loads are close in capacity to the DG systems; active detection methods have been proposed. Active methods perturb the connected circuit and then monitor the response to determine if islanding has occurred [5-8]. Active methods include: Impedance measurement method [9-11],Slip Mode Frequency Shift (SMS) [12], Active Frequency Drift (AFD) [13-19], Sandia Frequency Shift (SFS) [13, 20-22], Sandia Voltage Shift (SVS)[5, 8], Reactive Power Variation (RPV) method [23], and Mains monitoring units with allocated all-pole switching devices connected in series (MSD) [24]. Active methods attempt to create a power mismatch between the load and the DG when they are closely matched. It is possible that some of the active methods can cancel out the mismatch in an attempt to create one. It should also be noted that the positive feedback in some active methods could lead to power-quality degradation [25]. The injection signals can also induce some voltage waveform distortion.

Among frequency drift islanding detection methods, Sandia Frequency Shift (SFS) is considered as one of the most effective methods in detecting islanding conditions. The method can be used to improve the NDZ and THD by using a positive feedback gain, but still affect the power quality of the system. This paper presents a proposed technique to modify SFS anti-islanding method using Artificial Immune Systems (AIS). The method optimizes the parameters of the SFS method to reduce both the NDZ and the THD of the current waveforms.

AIS are computational paradigms that belong to the computational intelligence family and are inspired by the biological immune system. During the past decade, they have attracted a lot of interest from researchers aiming to develop immune-based models and techniques to solve complex computational or engineering problems.

The impact of the load parameters on the performance of the SFS method have been discussed in many papers [20, 21, 22, 27, 28, and 29]. However these papers concerned with reducing NDZ only and don't take into consideration the power quality deterioration. In [19] the performances of SFS method and its major factors affecting the phase-frequency characteristic of the islanding system were analyzed. Authors in [26] presented a passive method of detecting islanding of DG inspired by the information processing properties of natural immune system.

The remainder of this paper is organized as follows; Section 2 describes the SFS anti-islanding method, Section 3 introduces the problem formulation, Section 4 presents the modified SFS based AIS method and the AIS algorithm for solving this problem, Section 5 describes the system modeling and simulation, and Section 6 presents the results and discussion. Finally, Section 7 concludes the paper.

II. Sandia Frequency Shift Anti-islanding Method

Sandia Frequency Shift (SFS) is one of the active islanding detection methods that rely on frequency drift to detect an islanding condition. These methods depend on injecting a distorted current waveform into the original reference current of the inverter, therefore in the case of islanding operation the frequency drift up or down depending on the sign of the so called chopping factor "C_f". A positive feedback is utilized to prevent islanding and to decrease NDZ value. The procedures of applying the SFS method can be summarized as follow [24]:

1- Inject a current harmonic signal with a limited duration into the Point of Common Coupling (PCC) so as to comply with the maximum total harmonic current distortion (THD_i) allowed by interconnection standards.
2- The injected current signal distorts the inverter current by presenting a 0 A segment for drift up operation as shown in Fig. 1.

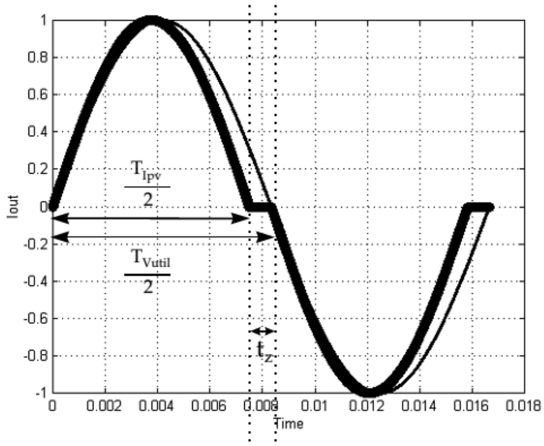


Fig. 1 SFS current reference of PV inverter

3- The desirable effect of the 0 A segment, is that the fundamental component of the inverter current leads the voltage by a small angle θ_{AFD}, which is frequency dependent and it creates a positive feedback.
4- When the grid is disconnected, the frequency of the voltage of the PCC tends to drift, reaching values higher until the frequency out of the OFP/UFP trip window (Range) and the inverter is disconnected.
5- A positive feedback is utilized to prevent islanding.

The non-detection zone (NDZ) of the SFS highly depends on its design parameters. The design parameters include both chopping factor C_f and feedback gain factor K. If these parameters are not properly tuned, it may result in failure of the method or deterioration of the system power quality through injection of high amount of harmonics. However, SFS may fail to detect islanding considering a fact that the deviations of voltage and frequency are small due to the power balance between DG sources and local loads.

The chopping factor is a function of the error in the line frequency and may be computed as:

$$C_f = C_{fo} + K(f_a - f_{line}) \quad (1)$$

Where C_{fo} is the chopping factor when there is no frequency error, K is an accelerating gain that does not change direction, f_a is the line frequency measured at PCC, and f_{line}, is the nominal line frequency.

III. SFS Parameter Optimization

The two parameters K and C_{fo} have different effect on the NDZ of SFS schemes. Initial chopping factor C_{fo} changes the location of NDZ on load space, but it doesn't change the size of NDZ. Increasing C_{fo} cause's adverse impact on power quality, as it perturb the network with a distorted current. The total harmonic distortion (THD) of the output current is directly proportional to C_{fo} [13]. According to the impact on power quality; smaller values are preferred in C_{fo} setting.

Positive feedback gain K has a positive impact on NDZ consideration. Increasing K will decrease NDZ and push the

NDZ towards load space with higher C_{fo}, but it may also produce negative impact on power quality of the distribution system. Therefore smaller values of K parameter are preferred for efficient detection of islanding. To minimize both NDZ and THD to acceptable limit, it is necessary to optimize the values of C_{fo} and K. In this paper AIS optimization technique is used to obtain optimal values of C_{fo} and K.

A. Objective function

The objective function is to minimize variable parameters of the SFS, which can be expressed mathematically as:

$$\text{Min}\,(\Delta F_o) = f_{omax} - f_{omin} \qquad (2)$$

where f_{omax} is the maximum value of load resonant frequency that will result in islanding operation, f_{omin} is the minimum value of load resonant frequency that will result in islanding operation, and they can be expressed as [31]:

$$f_{omax} = \frac{f_{max}}{2Q_f}\left(-\tan\theta_{SFS}(f_{max}) + \sqrt{\tan^2\theta_{SFS}(f_{max}) + 4{Q_f}^2}\right) \qquad (3)$$

$$f_{omin} = \frac{f_{min}}{2Q_f}\left(-\tan\theta_{SFS}(f_{min}) + \sqrt{\tan^2\theta_{SFS}(f_{min}) + 4{Q_f}^2}\right) \qquad (4)$$

$\theta_{SFS}(f)$ is the phase angle of the inverter and can be computed as:

$$\theta_{SFS}(f) = \frac{\pi C_f(f)}{2} \qquad (5)$$

B. Problem Constraints

Total harmonic distortion limits and accelerating gain limit are the main constraints for which the objective function in (2) is subjected:

i. Total harmonic distortion limits

Due to its negative impact on the power quality of the distribution system; THD must be limited to a preset value. According to IEEE Std.929-2000 limits THD must be lesser than 5% [30].

ii. Accelerating gain limit

The performance of the SFS is affected by the positive gain coefficient K. Better performance is achieved with larger values of K. Meanwhile increasing K will increase the current distortion and results in bad effect on system power quality.

The problem is solved using AIS to obtain the optimal values of both C_{fo} and K that minimize the NDZ and THD to acceptable values in a short time.

IV. Modified SFS–based AIS method

The immune system of vertebrates including human is composed of cells, molecules and organs in the body which protect the body against infectious diseases caused by foreign pathogens such as viruses, bacteria. To perform these functions, the immune system has to be able to distinguish between the body's own cells such as self cells and foreign pathogens such as non-self cells or antigens. After distinguishing between self and non-self cells, the immune system has to perform an immune response in order to eliminate non-self cell or antigen. Clonal selection theory explains how the immune system fights against an antigen. It establishes the idea that only those cells which recognize the antigen, are selected to proliferate. The selected cells are subjected to an affinity maturation process which improves their affinity to the selected antigens [32, 33].

AIS mimics these biological principles of clone generation, proliferation and maturation. The fundamental of AIS is inspired by the theoretical immune system and the observed immune functions, principles, and models [34, 35]. Today, the AIS techniques are used to solve complex problems in many areas that include engineering, science, computing, and other research areas. The following steps summarize the procedure of applying SFS–based AIS method to solve the islanding detection problem using SFS technique.

A. Antibody representation

In applying AIS to solve a problem; the solution of the problem is considered as a population of antibodies. In this study both C_{fo} and K are considered as antibody and each parameter is represented by a gene of antibody.

B. Initialization

The first step of applying the AIS method is the generation of initial population. The initial population is generated between a pre-defined minimum and maximum values using a random function. If the generated solutions do not fall into the feasible range, they are ignored and the generation process is repeated until the required number of solutions is generated. The size of the initial population is determined by making a trade-off between quality of a solution and computation time to yield that solution.

C. Affinity function

To introduce affinity (fitness) function, the variables should be put in the model and then the difference of the estimated values from the actual data for each antibody is calculated and in each generation the individual with minimum difference must be returned. Individual parameters are selected randomly and the affinity is calculated according to Euclidean distance [36]:

$$affinity(x, y) = \sqrt{\sum_{i=1}^{m} (x_i - y_i)^2 / m} \qquad (6)$$

D. Selection

In selection step, *n* antibodies with highest affinity are selected to generate a new population.

E. Cloning

The selected *n* individuals of the population that are cloned (reproduced) by the clonal process, giving rise to a temporary population of clones, *C*. The higher the affinity, the larger the number of clones generated for each of the n selected antibodies. Antibodies in the population must be cloned according to their affinity and generate a temporary population.

F. Mutation

The cloned antibodies are mutated to create a population *T*. During mutation, it assigns a lower mutation rate for higher affinity antibodies than low affinity antibodies. The idea is that the antibodies close to a local optimum need only be fine-tuned, whereas antibodies far from an optimum should move larger steps towards an optimum or other regions of the affinity landscape.

G. Reselection and diversification

This process reselects the improved antibodies from the population *T* to update it. Finally, the diversity introduction process replaces the low affinity antibodies with new ones.

A flowchart of the modified SFS –based AIS method is shown in Fig. 2.

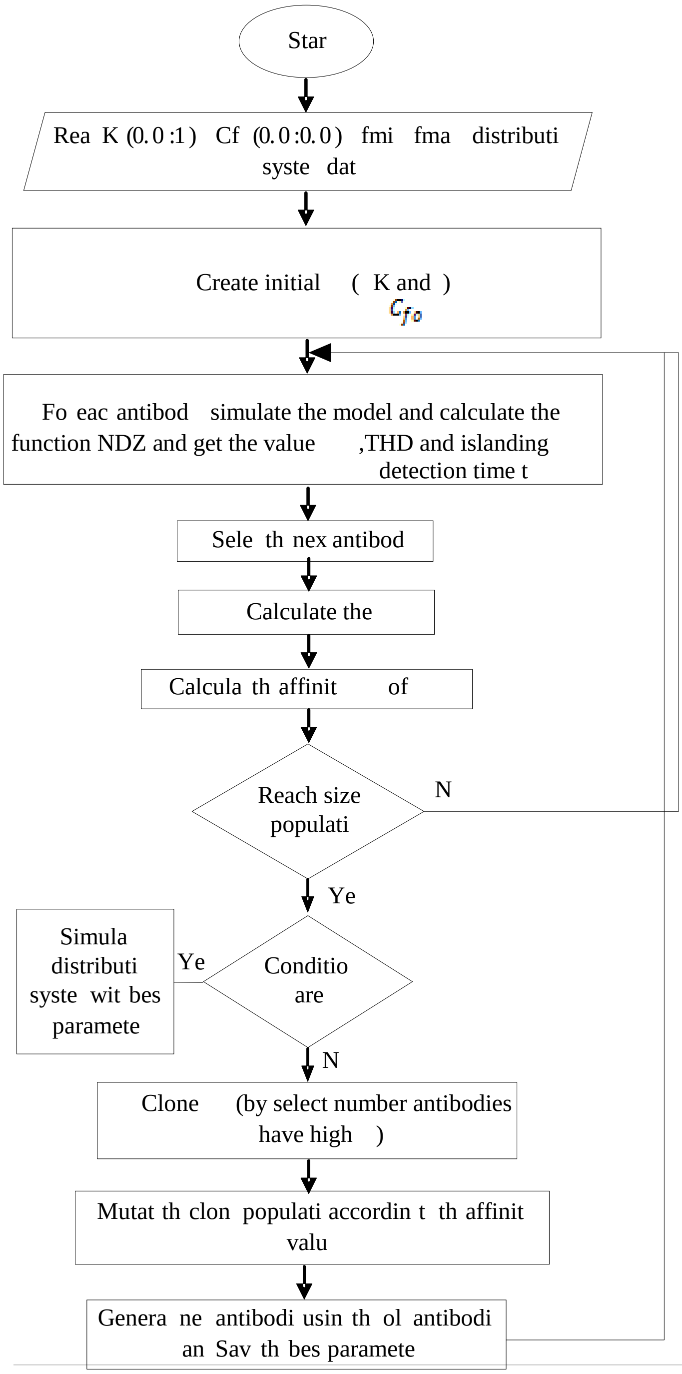


Fig. 2 Flowchart of the modified SFS –based AIS method

H. System modeling and simulation

To verify the proposed method and prove its effectiveness, it is applied to a test system shown in Fig. 3. The system consists of a PV array, connected to the grid PCC through a current controlled VSI inverter to supply a local ac load. The load can also be supplied by the grid through a power transformer.

The local load is represented by a parallel RLC with variable resonant frequency and quality factor. The utility breaker connects the grid to the PCC in case of normal operation. For islanding condition the breaker is opened at a prescribed time. The test system is modeled and simulated in MATLAB/Simulink environment. The simulation parameters are presented in Table (1). The simulation is implemented in the following steps:

- The frequency is firstly measured. If the frequency exceeds the IEEE. Std. 929-2000 limits, then the OFP/UFP will generate a fault signal to shutdown the inverter.
- In case that load and DG output are closely mismatched, then the frequency of the network is perturbed to create a power mismatch between load and DG.
- A variations in frequency can be detected by OFP/UFP system and consequently the DG is disconnected or shutdown.
- Since this perturbation signal may induce current and voltage waveform distortion, the load current is checked to ensure that the THD limits are not violated.

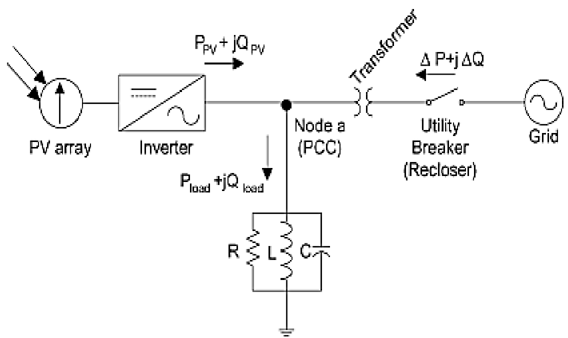


Fig. 3 Block diagram of the test system

Table 1: Simulation parameters

Grid voltage (rms)	400 V
Grid frequency	50 Hz
LC filter	L = 18 mH
	C = 30 μF
PV system output power	P_{inv} = 3 kW
	Q_{inv} = 0 Var

Parallel RLC load	R = 120Ω
	L = 153mH
	C = 67μF

V. RESULTS AND DISCUSSION

In this study the grid-connected current controlled inverter fed by a DC voltage source is disconnected after 0.228 sec. Both the conventional SFS and the proposed modified SFS –based AIS methods are applied to the test system and a comparison between the results is presented below.

A. SFS method

The conventional SFS method is applied to the test system shown in Figure 3. The simulation results show that: the feedback gain *K* equals to 0.096 and C_{fo} equals to 0.026 with a NDZ of 0.97359 and THD of 4.43%.

Fig. 4 illustrates the system response for detecting the islanding condition. The islanding is detected at 0.2372 sec. so that the DG is disconnected 9.2 ms after the grid disconnection (which occurs at 0.228 sec). Fig. 5 shows the voltage and load current waveforms during the simulation period, whereas Fig. 6 shows the frequency change after the grid disconnection.

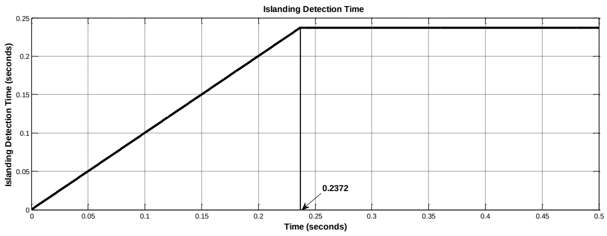
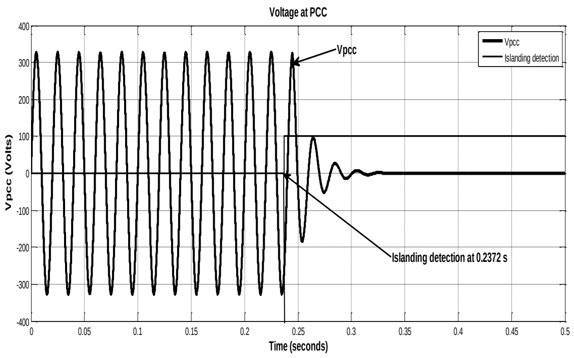
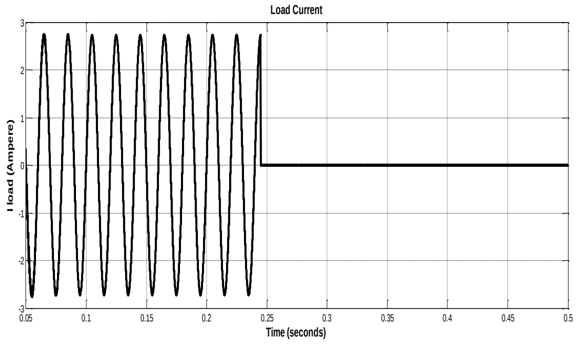


Fig. 4 System responses to detect island condition



a) Voltage at PCC



b) Load current

Fig. 5 Voltage and load current during simulation time

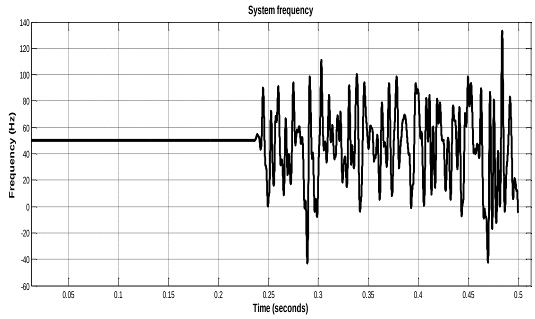


Fig. 6 Frequency changes during the simulation period

B. Modified SFS –based AIS method

In this case the modified SFS-based AIS method is applied to the studied system. Fig. 8 shows population and cloning of the best affinity values. The optimal values of the feedback gain *K* and C_{fo} are 0.108 and 0.036 respectively, with a NDZ of 0.970164 and THD of 3.91%.

Fig. 9 illustrates the system response for detecting the islanding condition. The islanding is detected at 0.22928 sec so that the DG is disconnected 1.28 ms after the grid disconnection. Fig.10 shows the voltage and load current waveforms during the simulation period, whereas Fig. 11 shows the frequency change after the grid disconnection.

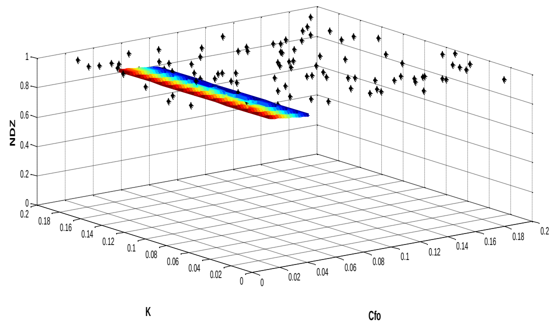


Fig. 8 Population and cloning of the best affinity values

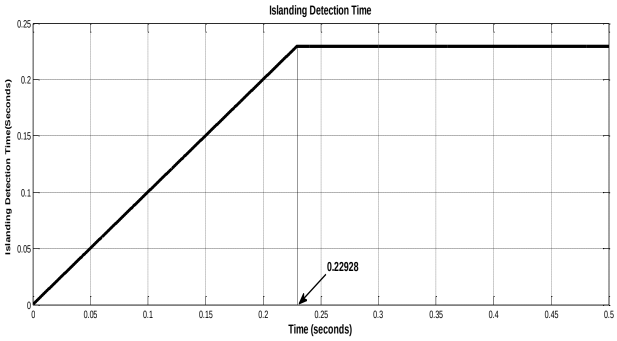
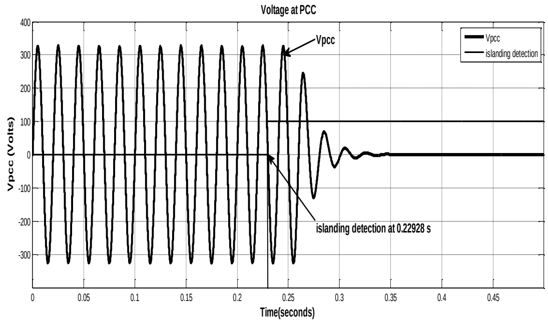
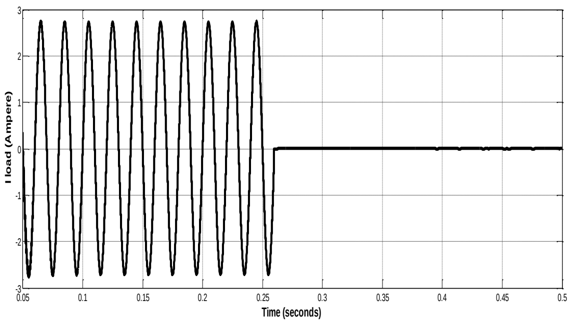


Fig. 9 System responses to detect island condition



(a) Voltage at PCC after applying AIS



(b) Load current after applying AIS

Fig. 10 Voltage and load current during simulation time after applying AIS

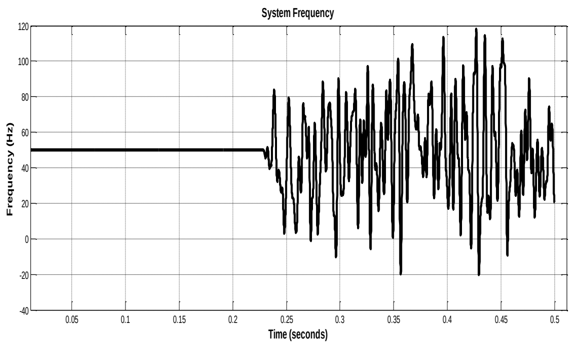


Fig. 11 Frequency changes during the simulation period

VI. Result analysis

The results show that conventional SFS has THD of 4.43% and the DG is disconnected 9.2 ms after the grid disconnection. In case of applying the modified SFS method the THD is 3.91% and the DG is disconnected after 1.28 ms from the grid disconnection. The proposed method decreases the time of islanding detection to just 13.9% of that attained by the conventional method. At the same time the proposed method decreases the THD to 88.26% of the THD obtained by the conventional method. It also reduces the NDZ. The results prove the efficiency and speed of the proposed method in islanding detection.

VII. Conclusion

This paper presents a proposed technique to modify SFS anti-islanding method using Artificial Immune Systems (AIS). The method optimizes the parameters of the SFS method to reduce both the NDZ and the THD of the current waveforms. A single-phase grid-tied photovoltaic distributed generation system was used to verify the method. A comparison between the proposed method and conventional SFS was presented and the results show that the proposed method generates less THD than the conventional SFS, which results in faster islanding detection and better non-detection zone. The deduced optimized parameter setting helps to achieve the "non-islanding inverter" as well as least potential adverse impact on power quality.

References

[1] W. Teoh, C. Tan, “An Overview of Islanding Detection Methods in Photovoltaic Systems”, World Academy of Science, Engineering and Technology Vol. 5, 2011.

[2] K. Tunlasakun, K. Kirtikara, S. Thepa, V. Monyakul, “A microcontroller based islanding detection for grid connected inverter” The 47thIEEE Midwest Symposium on Circuits and Systems, 0-7803-8346-X/04 © 2004 IEEE.

[3] A.Timbus, A.Oudalov and Carl N.M. Ho, “Islanding detection in smart grids”, Energy Conversion Congress and Exposition (ECCE),pp. 3631 - 3637, 2010 IEEE.

[4] M. Hanif, M. Basu and K. Gaughan, “A Discussion of Anti-islanding Protection Schemes Incorporated in a Inverter Based DG”,International Conference on Environment and Electrical Engineering (EEEIC), 10th International, 8-11 May 2011.

[5] D. Velasco, C. Trujillo, G. Garcerá and E. Figueres,"Review of Anti-Islanding Techniques in Distributed Generators",Renewable and Sustainable Energy Reviews,14 (2010) 1608–1614.

[6] M.Robitaille, K.Agbossou, M.Doumbia, and R.Simard,“Islanding Detection Method for a Hybrid Renewable Energy System”, International Journal of Renewable Energy Research, IJRER, Vol.1 , No.1, pp.41-53, 2011.

[7] M. Laour, A. Mahrane,F. Akel, M.Chikh and D. Bendib, “Implementation of Active Anti-islanding Methods Protection Devices for Grid Connected Photovoltaic Systems”, 6thInternational Conference on Computer and Electrical Engineering (ICCEE 2013)October 12-13, 2013, Paris, France.

[8] B. Álvarez, O. Rivera ,"Survey of distributed generation islandingdetection methods". Latin America Transactions, IEEE (Revista IEEE America Latina), Vol:8, No:5,pp.565 – 570, 2010.

[9] P. Mahat, B. Bak-Jensen, "Review of Islanding Detection Methods for Distributed Generation",Third international conference on electric utility deregulation and restructuring and power technologies, 2008, DRPT 2008. 6–9 April, 2008. p. 2743–8.

[10] P. Mahat,Z. Chen, B. Bak-jensen, "Review on Islanding Operation of Distribution System with Distributed Generation", Power and energy society general meeting,pp.1 – 8, 2011 IEEE.

[11] M. Roop, J. Ginn, J. Stevens, W. Bower, S. Gonzales, "Simulation and ExperimentalStudy of theImpedance Detection Anti-Islanding Method in theSingle Inverter Case".Photovoltaic Energy Conversion, Conference Record of the 2006 IEEE 4th World Conference on, Volume 2, pages: 2379 – 2382, May 2006.

[12] F. Liu, Y. Kang, Y. Zhang, S. Duan, X. Lin "Improved SMS Islanding Detection Method for Grid-Connected Converters", Renewable Power Generation, IET (Vol:4, No: 1,pp. 36 – 42, January 2010.

[13] F. Liu, Y. Kang and S. Duan, "Analysis and Optimization of Active Frequency Drift Islanding DetectionMethod" Applied Power Electronics Conference, APEC 2007-Twenty Second Annual IEEE, pages: 1379 – 1384, Feb. 25, 2007-March 1, 2007.

[14] Z. Ye, A. Kolwalkar, Y. Zhang, P. Du and R. Walling, "Evaluation of anti-islanding schemes based on nondetection zone concept," IEEE Transactions on Power Electronics, Vol 19, No 5, pp. 1171– 1176, September 2004.

[15] L. PhaniRaghav, T. Sandhya,"An Active Frequency Drift Method for an Islanding Detection of Grid Connected Microturbine Generation System", International Journal of Innovative Research in Science, Engineering and Technology-(ICETS'14), Vol 3, Special Issue 1, February 2014.

[16] A.Yafaoui, B. Wu, and S.Kouro, "Improved Active Frequency Drift Anti-islanding Detection Method for Grid Connected Photovoltaic Systems", IEEE Transaction on Power Electronics, , Vol. 27, No. 5, May 2012.

[17] L. Lopes, and Y. Zhang, "Islanding Detection Assessment of Multi-inverter Systems with Active Frequency Drifting Methods" IEEE Transaction on Power Delivery,Vol. 23, No. 1, January 2008.

[18] A. Yafaoui, B. Wu and S.Kouro, "Improved Active Frequency Drift Anti-islanding Method with Lower Total Harmonic Distortion",IECON 2010 - 36th Annual Conference on IEEE Industrial Electronics Society,pp. 3216 – 3221, 2010IEEE.

[19] W. Huang ,T. Zheng ,F. Yuan ,Z. Wang ,S. Xu, "Analysis of the NDZ Formulation Theory of Active Frequency Shift Islanding Detection Method for Grid Connected PV System", IEEEPower and Energy Engineering Conference (APPEEC), PES Asia-Pacific,pp. 1 – 5, 2013.

[20] H. Vahedi, and M.Karrari, "Adaptive Fuzzy Sandia Frequency Shift Method for Islanding Protection of Inverter Based Distributed Generation",IEEE Transaction on Power Delivery, Vol. 28, No. 1, January 2013.

[21] P.Du, Z. Ye, E. Aponte, J. Keith, and L. Fan, "Positive-Feedback-Based Active Anti-IslandingSchemes for Inverter-Based Distributed Generators:Basic Principle, Design Guideline andPerformance Analysis", IEEE Transaction on Power Electronics, vol. 25, no. 12, pp. 2941–2948, Dec. 2010.

[22] X. Wang, W. Freitas, and W. Xu, "Dynamic Non-Detection Zones of PositiveFeedback Anti-Islanding Methods forInverter-Based Distributed Generators" IEEE Transaction on Power Delivery,Vol. 26, No. 2, pp. 1145-1155 April 2011

[23] Y. Jung, J. So, G. Yu, J. Cho, "Modeling and Analysis of Active Islanding Detection Methods for Photovoltaic Power Conditioning Systems", Electrical and Computer Engineering, Canadian Conference(CCECE),Vol:2, 2004 IEEE.

[24] W. Bower and M.Ropp, "Evaluation of Islanding Detection Methods for Photovoltaic Utility-Interactive Power Systems",International Energy Agency, Report IEA PVPST5-09, 2002.

[25] P. Ray, N. Kishor, and S.Mohanty, "Islanding and Power Quality Disturbance Detectionin Grid-Connected Hybrid Power System UsingWavelet and S Transform" IEEE Transactions on Smart Grid,Vol. 3, No. 3, September 2012.

[26] G. Yin, "A Distributed Generation Islanding Detection Method Based on Artificial Immune System," Transmission and Distribution Conference and Exhibition: Asia and Pacific, 2005 IEEE/PES, pages: 1 – 4, 2005.

[27] J. Lee, B. Min, T. Kim, D. Yoo, and J. Yoo, "Active Frequency with a Positive Feedback Anti-islanding method based on a robust PLL algorithm for grid-connected PV PCS", Journal of Power Electronics, Vol. 11, No. 3, pp. 360 – 368, May 2011.

[28] H. Zeineldin, and M. Salama, "Impact of Load Frequency Dependence on the NDZ and performance of the SFS islanding detection method", IEEE Transactions on Industrial Electronics, Vol. 58, No. 1, pp. 139 – 146 January 2011.

[29] X. Wang, W. Freitas, W. Xu, and V. Dinavahi, "Impact of DG Interface Controls on the Sandia Frequency Shift antiislanding method", IEEE Transactions on Energy Conversion, Vol. 22, No. 3, pp. 792 – 794 September 2007.

[30] IEEE Std. 929-2000, IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems, Institute of Electrical and Electronics Engineers, Inc., New York, NY.

[31] Y. Zhang, H. Sun and L. Lopes "An islanding detection enhancer for a system with multiple photovoltaic inverters" 2nd Canadian Solar Buildings ConferenceCalgary, June 10 – 14, 2007 .

[32] L. de Castro and F. Von Zuben. "Learning and Optimization Using the Clonal Selection Principle", IEEE Transactions on Evolutionary Computation, Special Issue on Artificial Immune Systems, 6(3), pp. 239-251, 2001.

[33] L. de Castroand F. Von Zuben, "Artificial Immune System: Part 1 – Basic Theory and Applications", Technical report, Dec 1999.

[34] D. Dasgupta and N. Okine, "Immunity-Based Systems: A Survey", In Proceedings of the IEEE International Conference on Systems, Man and Cybernetics, Oct 1997.

[35] L. de Castro and J. Timmis, "Artificial Immune Systems : A Novel paradigm to Pattern Recognition", In Artificial Neural Networks in Pattern Recognition, SOCO-2002, University of Paisley, UK, 2002.

[36] X. Wang, J. Cheng, Z. Yin, M. Guo, "A new approach of obtaining reservoir operation rules: Artificial immune recognition system", Expert Systems with Applications 38 (2011) 11701–11707.